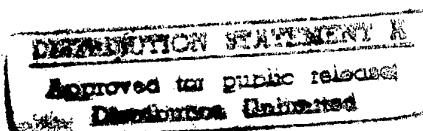


# THz RADIATION SOURCE THROUGH PERIODICALLY MODULATED STRUCTURES

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## 2 nd. Interim Report

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For the first time the technique of Hot Electron Spectroscopy is applied to the study of superlattice transport. Direct current spectroscopy of minibands in a field free, undoped superlattice is demonstrated. Miniband transport through the first and second miniband of three superlattices with different well widths as a function of the hot electron injection energy is observed. The obtained miniband widths and positions agree very well with theoretical calculation. The structure described in this work gives the highest energy resolution reported so far for electron current spectroscopy. A transfer ration of about 25% is obtained with the choosen transistor structure, giving an optimistic outlook for injection structures.

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2nd. Interim Report

Detailed investigation of electron dynamics and bandstructure effects in semiconductor superlattices are the basis for the understanding of carrier injection in these systems. The understanding of carrier injection is the basis for the realization of semiconductor THz sources.

The second period of this project was dedicated to studies of undoped GaAs/GaAlAs short period superlattices with different well widths using the technique of hot electron spectroscopy. Decreasing the barrier thickness of multiple quantum well structures leads to stronger coupling between the degenerate eigenstates in the wells and thus to the formation of superlattice minibands. Since the periodicity or the barrier/ well relation can be intentionally varied over a wide range while leaving the other parameters unchanged, a systematic exploration of electrons in a periodic potential becomes possible. In the absence of perturbations to the periodic crystal potential, the electronic states are extended over the entire superlattice and the energy spectrum consists of allowed energy bands separated by forbidden gaps. To prevent the collapse of the extended electronic states into localized states in the wells, the electric field in the superlattice has to be small and the mean free path of the carriers in the range of the superlattice dimensions.

The measurements are carried out using a hot-electron transistor as an electron spectrometer. An energy tunable electron beam is injected via a tunneling barrier into the field free superlattice and the transmitted collector current is measured as a function of the injector energy. Significant increase of the collector current is observed due to miniband conduction in the superlattice.

Experiments of hot electron transport in high quality, undoped, field free GaAs/Ga<sub>0.7</sub>Al<sub>0.3</sub>As superlattices have been performed, where the influence of electron-electron and electron-impurity scattering can be neglected. Under flat band condition, there is no Wannier-Stark splitting, which would lead to a localization of electrons in the wells, and consequently to a reduction of the transmittance of the ballistically injected electrons.

A three terminal device is used to probe the superlattice properties. In these devices an energy tunable electron beam is generated by a tunneling emitter with an energy distribution parallel to the growth direction of about 20 meV (FWHM). The electrons traverse a thin highly doped GaAs region (base), pass a very low doped drift region, followed by the strongly coupled superlattice. Electrons having an energy in the range of the superlattice minibands will pass the superlattice and finally be collected by a doped GaAs layer. Electrons reflected by the minigaps or scattered in the drift region are collected by the thin base contact.

The heterostructures studied are molecular beam epitaxy (MBE) grown heterostructures consisting of the following common features: A highly doped n<sup>+</sup>-GaAs collector contact layer ( $n=1\times 10^{18} \text{ cm}^{-3}$ ) is grown on a semiinsulating GaAs substrate. Followed by a superlattice and the drift regions which are slightly n-doped ( $\sim 5\times 10^{14} \text{ cm}^{-3}$ ), in order to avoid undesired band bending. To reduce quantum mechanical confining effects originating from the quantum well formed by the emitter barrier and the superlattice the drift region is chosen to be at least 200 nm in width. As found in previous experiments, about 75% of the injected electrons traverse the base ballistically. It should be noted that the half width of the injected electron beam limits the energy resolution of the experiment. Finally, a n<sup>+</sup>-GaAs contact layer ( $n=1\times 10^{18} \text{ cm}^{-3}$ ) is grown on top of the heterostructure to form the emitter.

In summary direct experimental current spectroscopy of minibands in a field free, undoped superlattice using the technique of Hot Electron Spectroscopy is demonstrated. Miniband transport through the first and second miniband of three superlattices with different well widths as a function of the hot electron injection energy is observed. The obtained miniband widths and positions agree very well with theoretical calculation. The structure described in this work gives the highest energy resolution reported so far for electron current spectroscopy.

The manuscript "Ballistic Electron Spectroscopy of Vertical Superlattice Minibands" by C. Rauch, G. Strasser, K. Unterrainer, B. Brill, and E. Gornik has been submitted to Appl. Phys. Lett.